JP1.15 GLOBALLY UNIFIED MONSOON ONSET AND RETREAT INDEXES

Xubin Zeng* and Er Lu

The University of Arizona, Tucson, Arizona

1. INTRODUCTION

Monsoon is one of the key elements of the global climate system and strongly affect agricultural and other human activities in the monsoon regions (e.g., Webster et al. 1998). Its onset, retreat, and geographical extent are basic monsoon characteristics, and have been studied for decades (e.g., Ramage 1971). The most fundamental driving mechanisms of a monsoon system include the differential heating of the land and ocean, the moist processes that determine the strength, vigor, and location of the major monsoon precipitation, and the rotation of the Earth (Webster 1987). The seasonal reversal of wind direction over monsoon regions (e.g., India) has been noted for thousands of years (Warren 1987), while the attempt to understand monsoon meteorology based on physical principles began over three hundred years ago (Kutzbach 1987). The onset of the summer monsoon is generally concurrent with a reversal or major change in the wind field, an abrupt rise in precipitation and water vapor, and a drastic change in other variables (e.g., kinetic energy). Partly for this reason, different criteria have been used to define the monsoon onset and retreat over different monsoon regions (Das 1987; Tao and Chen 1987; Hendon and Liebmann 1990; Douglas et al. 1993; Murakami and Matsumoto 1994; Li and Qu 1999; Wu and Wang 2000) and even over different parts of the same monsoon region (Higgins et al. 1999), which make it very difficult to intercompare and understand the short-term and intraseasonal variability of the monsoon over various monsoon regions.

*Corresponding Author Address: Prof. Xubin Zeng, Department of Atmospheric Sciences, The University of Arizona, Tucson, AZ 85721; e-mail: xubin@atmo.arizona.edu

2. DATA AND PROPOSED CRITERION

Three different datasets have been widely used to study monsoon onset and retreat in the past: surface meteorological station data (e.g., precipitation, dew point temperature), radiosonde data (e.g., wind field), and satellite outgoing longwave radiation (OLR) data. However, each of these datasets has serious limitations; for instance, the relation between OLR data and precipitation over land is not as good as that over ocean; and the relation becomes much worse at daily time scales. Precipitable water (PW) data were also used in Cadet (1986) over the Indian Ocean during the 1979 summer monsoon. More recently, the climatological pentad (5-day) mean rainfall data, which were derived by merging the satellite estimates, surface gauge measurements, and numerical model outputs (Xie and Arkin 1997), were used in Wang and LinHo (2002) to study the rainy season of the Asian-Pacific summer monsoon.

Here we intend to use the global daily PW data on $1^\circ \times 1^\circ$ grids from January 1988 to December 1997 (Randel et al. 1996). These data combine water vapor retrievals from satellite infrared and microwave sensors with radiosonde data, and hence are ideal for the study of the short-term and intraseasonal variability of monsoon (including its onset and retreat). As mentioned earlier, the abrupt rise (or decrease) of water vapor is one of the features associated with the monsoon onset (or retreat). Furthermore, the quantitative relationship between precipitation, cloud-top temperature, and PW between 40°N and 40°S has been established (Zeng 1999).

First a normalized precipitable water index (NPWI) is defined:

$$NPWI = \frac{PW - PW_{min}}{PW_{max} - PW_{min}} \qquad (1)$$

where PW is the daily precipitable water at each $1^\circ \times 1^\circ$ grid, and PW_{max} and PW_{min} are the ten-year averages of the annual maximum and minimum daily PW at each grid respectively. Then, the following objective criterion is proposed to define the globally unified monsoon onset (or retreat) date:

The monsoon onset (or retreat) date for grid cell G is defined as the first day (d) when NPWI is greater (or less) than the Golden Ratio (0.618) for 3 consecutive days in 7 of the 9 cells centered at cell G[1] *in day d or (d±1).*

The consideration of '3 consecutive days' is consistent with the current practice over different monsoon regions. Since the monsoon onset represents a large-scale change of weather patterns, the use of '9 cells' helps to remove the spurious early onset due to the intraseasonal variability (e.g., in precipitation and water vapor) during the pre-monsoon period (Flatau et al. 2001). Compared with the onset and retreat dates using local wind and precipitation criteria that are available over various monsoon regions in different years, we found that the onset and retreat are always corresponding to a roughly fixed stage of the annual cycle of PW, even though both PW_{max} and PW_{min} are quite different over different regions. Specifically, a threshold value of 0.6 to 0.63 for NPWI was found to work adequately. Hence we choose the Golden Ratio $[(\sqrt{5}-1)/2 = 0.618]$ which is the solution of $(1-x)/x = x/1$. The Golden Ratio, after all, is present in the growth patterns of many things in nature (probably including the evolution of monsoon), and it has long been used by artists (e.g., Leonardo da Vinci) and architects, and more recently by scientists. Its use here, however, does not imply that all the decimal points associated with this irrational number are needed.

Quantitatively, monsoon regions should have identifiable monsoon onset and retreat dates as well as a long enough monsoon duration. Furthermore, they should have relatively high PW during the wet summer and relatively low PW during the dry winter. Over non-monsoonal regions with relatively small $(PW_{max} - PW_{min})$, however, Eq. (1) may amplify small variations in PW, and the above criterion may give spurious monsoon onset and retreat dates. Therefore, the above criterion should be applied to monsoon regions only.

[1]If one or more of the 9 grids are undefined, e.g., at the edge of monsoon regions, the required number of 7 is correspondingly reduced.

A consensus on the global geographical extent of monsoon has not been reached yet. Using a rather strict definition of a monsoon based on both wind reversal and seasonal precipitation criteria, Ramage (1971) identified only African, Asian, and Australian regions as monsoon regions (35°N−25°S, 30°W−170°E). Higher latitudes over east Asia have also been included in recent studies (e.g., Wang and LinHo 2002). Later, justification was given for considering North America as a monsoon region based on the seasonal precipitation criterion and the seasonal surface wind reversal over some areas (Douglas et al. 1993). Zhou and Lau (1998) also suggested that South America qualifies as a monsoon region based on the seasonal precipitation criterion and the fact that the wind reversal becomes apparent after the strong annual mean wind is removed.

Here, for convenience, we only consider grid cells satisfying two conditions: (a) both the monsoon onset and retreat dates are defined, and (b) the difference between the annual maximum and minimum monthly PW averaged over the ten-year period (1988−1997) is greater than 18 mm. The threshold value of '18 mm' is chosen to ensure that all monsoon regions mentioned above are included and the monsoon duration (i.e., retreat minus onset dates) at each of these cells is longer than 50 days. However, it also results in the inclusion of some nonmonsoonal regions, which will be further discussed later.

Over different monsoon regions, our onset and retreat dates are found to be consistent with those determined using local wind and precipitation criteria. The use of a single onset/retreat criterion globally also enables us to suggest the existence of two branches of the North American monsoon system, just like its counterpart in Asia. Detailed discussion of results is given in Zeng and Lu (2002), and will be presented in our talk.

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